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# Bandwidth and chirp characterisation of wavelength conversion based on electroabsorption modulators

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**Abstract** It is demonstrated experimentally that the frequency chirp of a data modulated signal can be reduced and the modulation bandwidth increased through wavelength conversion in an electroabsorption modulator.

## Introduction

The electroabsorption modulator (EAM) has proven to be a versatile component in ultra fast WDM and OTDM systems with its ability to perform several different functionalities, yet remaining a simple structure. Recently, all-optical functionalities based on cross-absorption modulation (XAM) have been shown to possess certain regenerative properties, resulting in improvements of receiver sensitivity [2] and in transmission performance [1, 3] upon wavelength conversion. Furthermore, all-optical demultiplexing based on XAM has proven beneficial [2, 4]. So far the focus, when using XAM for wavelength conversion and regeneration, has been on the improvement of the extinction ratio and the suppression of noise, in particular in the zero level of the converted data signal. In this paper, we report on additional advantages of using XAM in an EAM for wavelength conversion; namely that the bandwidth of the component may be increased by optical modulation and that the chirp of the converted signal may be tuned to be less than that of the original data. This finding strongly encourages the use of EAMs for wavelength conversion in high bit rate long-haul systems where cascading several wavelength converters is very frequent.

## Experimental procedure

The experimental set-up is shown in Figure 1, and is based on a novel approach to small signal modulation of the EAM's absorption. In a conventional small signal measurement, the EAM is electrically modulated around a dc bias by an rf signal with a small amplitude. In this experiment, the absorption of the EAM is modulated optically. This is achieved by letting a network analyser (NA) electrically modulate (e/o) the first EAM (EAM 1 in Figure 1), and then use this modulated light to modulate the absorption of EAM 2. This technique allows for the assessment of the all-optical (o/o) bandwidth, which essentially determines the obtainable bit rate that may be either wavelength converted or all-optically demultiplexed. Furthermore, when transmitting the modulated light over a length of fibre, the modulated sidebands of the optical spectrum will have different propagation speeds due to the dispersion of the fibre, which will lead to resonance dips in the frequency spectrum of the transmitted light. Thus, modifying the fibre-response method developed by Devaux [5] for

measuring the e/o chirp  $\alpha$ -parameter, now allows for an evaluation of the chirp after wavelength conversion.

The EAMs used in this paper are MQW devices with 10-15 quantum wells of varying depth and with varying electrical capacitance. The devices are provided by Giga-An Intel Company.

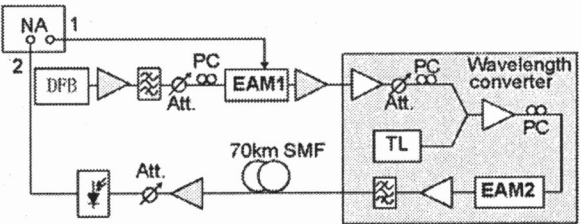


Figure 1. Experimental set-up. NA: Network analyser, TL: Tunable laser, PC: Polarization controller.

A cw laser beam at 1547 nm (DFB in Figure 1) is injected into the reverse biased EAM 1 where it is modulated through the Quantum Confined Stark Effect (QCSE) as controlled by the rf voltage from the NA. The e/o frequency response curve is measured for reference. After this, the e/o light is amplified and combined with a tuneable cw source (TL) for wavelength conversion in EAM 2. The e/o modulated light acts as the pump that saturates the absorption of the TL probe, and thus the modulation is transferred to the new TL wavelength. An optical filter blocks the original wavelength. The o/o response is determined from the measured frequency response curve by subtracting the measured e/o response. By transmitting the o/o light over 70 km of standard SMF fibre, the o/o chirp can be evaluated.

## All-optical bandwidth results

The o/o bandwidth is measured on three component types with different quantum well depths and different bonding pad sizes. Type 1: Deep wells, small pad, type 2: Shallow wells, large pad and type 3: shallow wells, small pad. Figure 2 shows the o/o frequency response curves for all three types with the bias and pump/probe power settings for optimised performance as an inset. Since the modulation and the response is optical, the scale is shown in optical dB [dBo] (to convert to electrical dB [dBe], the scale

should simply be multiplied by a factor of 2).

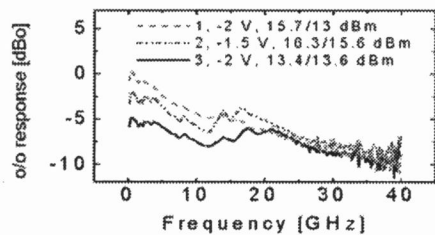


Figure 2. Optical-to-optical frequency response from three different QW structures.

The curves show that shallow wells are important for obtaining a high o/o bandwidth. Table 1 summarises the 3 dB bandwidths and compares them to e/o bandwidths.

Q.W. depth	Deep	Shallow	Shallow
Pad	Small	Large	Small
	(type1)	(type2)	(type3)
e/o, -3 dBe	> 20 GHz	16 GHz	24 GHz
o/o, -3 dBe	5 GHz	19 GHz	24 GHz

Table 1. Summary of -3 dBe bandwidths for e/o and o/o small signal modulation.

The results in Table 1 show that e/o modulation is much more dependent on the electrical pad capacitance of the device than is the case for o/o modulation. On the other hand there is a very dramatic dependence on the well depths for o/o modulation (e.g. deep wells: -3 dBe at 5 GHz, shallow wells: 24 GHz). A component of type 2 with a large pad capacitance can have its modulation bandwidth improved when using o/o. This component has previously been shown to enable 80/10 all-optical demultiplexing, but could not perform 40/10 e/o demultiplexing.

All-optical chirp results

Figure 3 shows the measured frequency response of the o/o light after transmission through 70 km of SMF fibre. From the positions of the dips,  $\alpha$ -parameters can be deduced [5]. In this experiment we investigate the influence of reverse bias and probe wavelength on chirp values of the wavelength-converted signal. With a fixed bias on EAM1, the transmission response at different EAM2 biases is measured; the results are shown in Fig. 4 (a). The trend of a reduced  $\alpha$  value with increased bias is clearly seen; zero chirp is obtained around -2.3 V. This bias dependence agrees with the case of electrical modulation, which can be understood by considering that pump-generated carriers have an effect similar to that of electrical modulation by screening the external field.

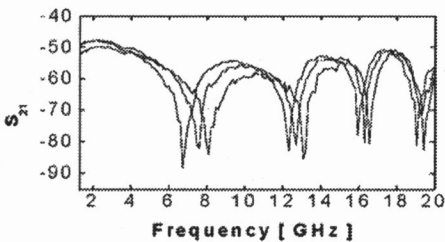


Figure 3. Resonance dips in the frequency spectrum after transmission reveals the chirp.

The independence of  $\alpha$  values on input chirp, which in all cases is higher than the output chirp, suggests the capability of an EAM-based wavelength converter to reduce chirp and even possibly generate negatively chirped signal.

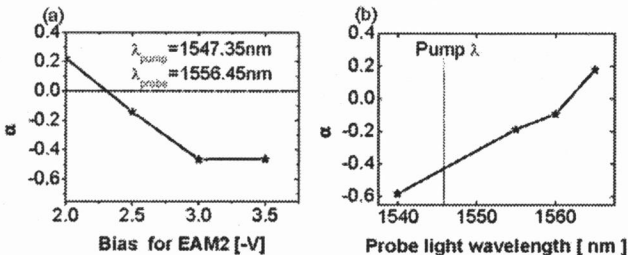


Figure 4.  $\alpha$ -parameter versus (a) bias and (b) wavelength.

In fig. 4 (b), where the bias of EAM2 is -2.5 V and the original signal is fixed at 1546 nm, it is shown that shorter probe wavelengths have lower  $\alpha$  values, and zero chirp is achieved around 1561.7 nm. From these results it can be concluded that there is a possibility, by optimising the bias and the wavelength, to lower or achieve completely negative  $\alpha$  by EAM-based wavelength conversion.

Conclusions

We have experimentally characterised the bandwidth and chirp characteristics for EAM-based all-optical wavelength conversion. It is shown that optical modulation can both increase the modulation bandwidth and lower the chirp.

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